A crack-on-chip testing method applied to freestanding ultra-thin films from brittle to ductile down to 2D materials

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Abstract

The characterization, control, and enhancement of the cracking resistance of freestanding thin films and 2D materials are major concerns for flexible electronics, MEMS/NEMS devices, and structural or functional coatings. In particular, environmentally-assisted cracking phenomena affect the reliability of many thin films/2D materials-based systems. As a result of, for instance, adsorption, absorption, and surface reaction mechanisms with oxygen or moisture. This is a complex subject, along with the determination of the fracture toughness that constitutes an important subject that is insufficiently studied mostly because of experimental challenges. The objective of the present research is to present a new on-chip technique able to extract the static fracture toughness and to study the environmentally-assisted crack growth in freestanding thin films, 2D materials, and as well multilayers built from a combination of these films and 2D materials. The present method relies on a residual-stress-based-on-chip concept taking advantage of MEMS-based fabrication principles without a need to monopolize any external equipment. The test configuration consists of a notched specimen attached to two long actuator beams involving tensile internal stress. Upon release, the relaxation of the residual stress leads to the deformation of the specimen. A crack initiates at the notch tip, propagates, and finally arrests. Several materials were tested with this method varying from brittle materials like silicon nitride (SiN), silicon dioxide (SiO_2), alumina (Al_2O_3) to ductile materials such as copper (Cu), and nickel (Ni). This technique was also applied to multilayers constituted from brittle and ductile materials. 2D materials like graphene (Gr) and heterostructures of graphene and hexagonal boron nitride (hBN) were also successfully studied. The combined experimental and finite element studies determine the static fracture toughness and provide an insight into the variation of the crack growth rate (*da/dt*) as a function of the stress intensity factor (*K*) under different temperature conditions and humidity levels.